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FOREIGN TECHNOLOGY DIVISION

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by

Xu Fei

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RESEARCH INTO SEVERAL PRACTICAL USES FOR THE BLOWN FLAP TECHNIQUE

Xu Fei

In the past 10 years there have already been quite a few articles which have reported that the blown flap technique was capable of obviously improving many types of aircraft characteristics under conditions in which the aircraft is operating at low speeds and with an attack angle of less than 30°. For example, if one uses a blown flap at the place where the taper of the forward edge of the wing thins the wing down, then it is possible to make an improvement in the non-linear lifting force. If one uses a blown flap at a place in the vicinity of the leading edge of the rear flaps, then it is not only possible to increase the effectiveness of the flaps themselves, but it is also possible to add to the effective lifting power of the main body of the wing itself. When the same technique is used on other lifting surfaces, such as the standing tail and the horizontal tail surfaces as well as the forward edges, it is also possible, in all these cases, to obtain relatively large improvements in the aerodynamic capabilities involved.

In the last few years the agencies responsible for aviation research in several countries as well as several aircraft manufacturing companies have shown an increasingly lively interest in this area of research. Worthy of particular attention are the following several directions in which the research has gone or will go: 1) the work of researching the technology of a blown flap has not been confined only to the area of examining the mechanisms involved; this research has already passed on to the concurrent study of practical designs; 2) the range of the angles of attack which have been included in the research has been expanded to include angles as large as 90°; 3) the range of speeds which are included in the research has also been extended to include the realm of transsonic speeds. The preliminary results of this research indicate clearly the fact that it is possible for the technology of the blown flap to introduce

obvious improvements in the longitudinal and lateral aerodynamic characteristics of aircraft under conditions in which there is a large angle of attack. This research also indicates that this technology is capable of making significant reductions in the separation phenomena induced by the shock waves which are attendant on flights at transsonic speeds and in cases in which the vibrations which come from very large angles of attack are a factor. The fact that this technology has such a capability demonstrates that it has a potential for use in the designs of the fighter aircraft of the future. The purpose of this article is to give a short introduction to the subjects which have been mentioned above.

1. The influence of the blown flap technique on the low speed capabilities of the F-5E

Like the F-16, F-17 and F-18 fighters and others, the F-5E also makes use of a compound wing arrangement with an added wing on the side edge. This is a type of arrangement which will not only cause the fighter to have advanced transsonic and supersonic speed capabilities, but also will make it possible for the same aircraft to have excellent low speed capabilities as well. This is a relatively good arrangement for the accomplishment of this dual purpose. If one is dealing with moderate angles of attack and larger, then the employment of the added strip of wing on the leading edge of the main wing and the detached vortices which it produces makes it possible to obtain relatively large amounts of vortical lift. Moreover, this sort of wing arrangement extends the vibration threshold of the wing as well as the stall threshold. However, when one is dealing with an angle of attack of approximately 24°, then the wing strip vortices become hard to maintain and they break up. As a result of this phenomenon, there is a limitation placed on the usable range of the aircraft capabilities in this area. The Northrup Aircraft Company during the water flow analysis which it did on the F-5E, discovered the fact that if one uses a simple tube or pipe as a blown flap at a sweepback angle of 55°, then one not only completely eliminated the separation flow on the wing but also added to the edge

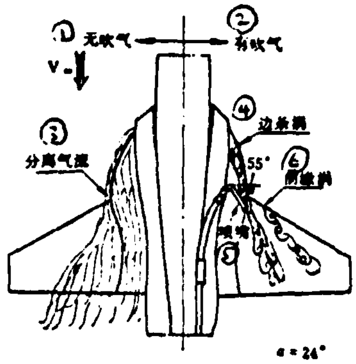
vortex and induced a vortex on the leading edge of the wing. For an illustration of this, see Figure 1. This experience was sufficient to cause the Northrup company, on the basis of its use of the blown flap technique on the F-5E, to later make a complete evaluation of the aircraft and this new technique.

This experimentation was carried out in the Northrup company's 7x10 foot wind tunnel. For a view of the external form of the surface of the model, see Figure 2; the interior diameter of the jet intake was 0.132 inches. At the point of contact , between the leading edge strip and wing, the M number used during the test was 0.18; the average aerodynamic arc length Re number was 1.02×10^6; and, with differing coefficients for the amount of blowing ($C\mu = 0.02 \sim 0.12$) and for the sweepback angle ($\Lambda = 55°$ and $70°$), observations were made of the longitudinal and lateral characteristics of the entire aircraft.

The results of experimentation demonstrate that when one is dealing with angles of attack larger than 10°, the use of the blown flap technique induces even larger amounts of vortical lift. Moreover, the use of this technique under such circumstances causes an angle of attack for the aircraft as a whole which results in the stall speed being extended from the original 24° to 32° or even more and it causes a very clear improvement in the lift-to-drag characteristics of the aircraft when one is dealing with large angles of attack for the aircraft as a whole. Besides this, the use of the blown flap technique causes a very small moment of lift on the forward or nose section of the aircraft. In fact, a moment of lift is almost equal to zero. This causes the linear portion of the force moment curve to be extended to even larger angles of attack and this extension has no influence on the stability of the aircraft as a whole. One thing which particularly needs to be pointed out is that there is an influence on the lateral performance of the aircraft as a whole which is exerted by the use of the blown flap technique on the F-5E. From Figure 3, it can be seen that when one

Figure 1. An examination of the water tunnel flow spectrum for a 1/40 scale model of the F-5E (a = 24°)

Key: 1--no blast; 2--with the presence of blast; 3--separation flow; 4--edge vortex; 5--jet nozzle; 6--leading edge vortex



is dealing with a situation in which the angle of sideslip is -10° and the angle of attack is larger than 8°, then the use of this blown flap technique induces even larger increases in the amount of asymmetrical lift. This results in an obvious and advantageous increase in the rolling moment. Besides this, in the case of another aspect of the problem, when the angle of attack is increased to as much as 20°, if the blown flap technique is not used, the air flow along the surface of the wing will give rise to severe separation phenomenon. When this phenomenon takes place the edge vortex has already broken up and the wake from this type of edge vortex is capable of causing the effectiveness or efficiency of the tail to go into a very steep decline. Due to these conditions, the curve for the moments of yaw (the curves for the lateral forces are also similar) experience a strong increase. As for the effects which appear after blowing, the stall speed for the wing involved is postponed or pushed back. On the other hand, there is an increase in the edge vortices. Due to these developments, there is a consequent increase in the blowing magnitude; the efficiency of the tail increases and the moments of yaw and the lateral force characteristics also experience an improvement.

In order to investigate the results of using different trim set-ups on the flaps of the aircraft and the interaction between these trims and the blown flap technique, we also carried out a set of comparative experiments with the forward or leading flaps and the trail flaps set at respectively 24° and 20°. We obtained results by

using the blown flap technique and other results when the technique was not used. The results of these tests demonstrated that the use of the blown flap technique is capable of improving the longitudinal characteristics of the aircraft as a whole. However, the tests also revealed that the effects of this technique on the lateral characteristics of the aircraft are not great. Besides this, it was discovered that when the leading edge flaps had a trim, then the advantageous influence of the blown flap technique on the wing of the aircraft was diminished. In such a situation, the use of the technique was primarily responsible for the strengthening of the edge vortices and that is all.

During these tests, the coefficients which were used for the amounts of blowing were $C\mu = 0.02\sim0.12$ and these values corresponded respectively to amounts of engine flow in the F-5E of 7%-33%. After going through the process, it was found that the blown flap technique actually reduced the residual power which is stipulated for use during evasive maneuvers. If one is speaking in terms of the sort of fighter aircraft which are currently in use, this reduction of the amount of flow through the engine is unacceptable. Because of this problem the blown flap technique can only be used in cases in which one is designing engines which are not too sensitive to thrust losses and have high bypass ratios. Only in the case of such engines will it be possible to use this technology in the design of the fighter aircraft of the future.

2. The use of the blown flap technique under conditions in which the angle of attack is very large

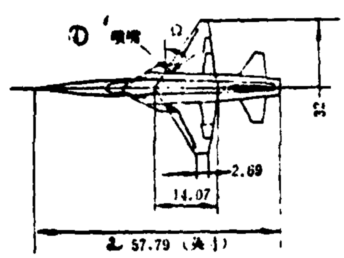
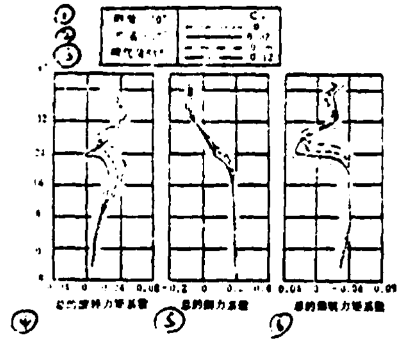


Figure 2. A planar view of a 1/10 scale model of the F-5E (dimensions are all in inches)
1--jet nozzle or mouth; 2 --inches

Figure 3. The influence of the blown flap technique on the lateral characteristics of the aircraft involved

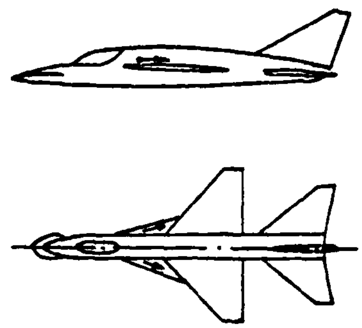
1--sideslip; 2--horizontal stabilizer; 3--jet angle; 4--the overall coefficient of roll moment; 5--the overall coefficient of lateral force; 6--the overall coefficient of the moment of yaw



If one is considering measures which can be applied to today's advanced aircraft in order to improve their flight characteristics when they are operating with large angles of attack (measures such as large leading edges on the wings or the operation of the flaps in particular ways as has already been discussed earlier in this article), then one must accept the fact that the range of angles of attack with which these methods can be employed is limited (it is limited to within a range of approximately 30°). When the angles of attack are increased to values larger than this, counterproductive effects occur. Unlike these other methods of improving operational characteristics, the blown flap technique is certainly not limited to any range of angle of attack. This special characteristic of this technology presents the possibility of making the operational ranges within which aircraft can fly even larger than they are now. The aerodynamic mechanism which forms the foundation for the blown flap technique is similar to the theoretical foundations of leading edges on wings. It is not difficult to come up with the idea of combining this new technique and large leading edges on wings. The use of these techniques together would certainly raise the operational characteristics of fighter aircraft to an even higher level. Below we will present a short introduction to the results of experiments into the possibility of using this type of arrangement.

Figure 4 is a diagram of the model which was used in these experiments. The aspect ratio of the wings is 3.2; the sweepback

Figure 4. A diagram of the model which combines the blown flap technique and the placement of large leading edges on the wings



angle of the leading edges is 32° and the tip-to-base ratio is 0.3; moreover, the wings have a twist. The sweepback angle of the leading edge extension at the front of the wing is 75°; its area is 11% of the area of the wing and there is a jet nozzle at the place where the aspect ratio is 10%; the sweepback angle of the blowing flow is also 75°; the experiments were carried out in the eight meter wind tunnel at ONERA and the range of angles of attack which was used was 0°-90°, $C\mu = 0 \sim 0.2$.

The results of these experiments demonstrate that the blown flap technique employed with the very large angles of attack above 30° has the following two effects:

1. It increases the total lift of the aircraft; moreover, it results in relatively large improvements in the moment of lift on the nose of the aircraft as well as in the trim characteristics of the aircraft. Figure 5 gives measurement results for the lift characteristics for various coefficients of amounts of blowing. The broken lines in the figure are lines of continuity for the points of trim which correspond to various types of configurations. It can be seen that when the angles of attack are greater than 70°, all blowing cause relatively obvious increases in the amounts of lift. For this type of arrangement then, due to the fact that the position of the increase in lift is produced by the interference between the jet flow and the vortical flow is forward, the trim characteristics of the aircraft improved; see Figure 6.

2. Let us consider the problem of improving the vibration characteristics of an aircraft. Based on results of tests which were run on certain fighter aircraft both in the air and in wind tunnels, discontinuous detached vortices on the wings can cause vibrations in the aircraft. If it is possible, from a certain appropriate location, to blow out a set of small but relatively high speed air flows in order to convert the detached vortices into one stable vortex and reduce the pressure pulsations of the air flow on the wing surface it becomes possible to delay the occurrence of vibration. Of course, if one is doing a precise determination of the vibration characteristics of a wing, it is still necessary to do a detailed analysis of the aerodynamic structures involved. However, from several analyses of aerodynamic qualities of objects, it is also possible to obtain some indirect but reliable information on vibration characteristics.

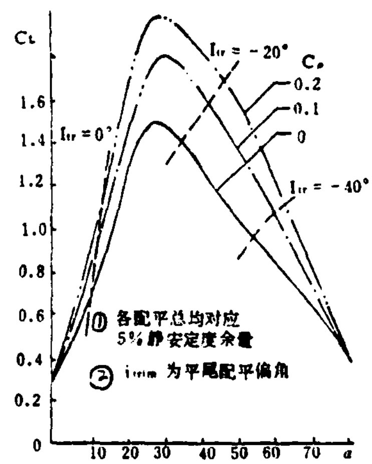


Figure 5.

1--various trims which correspond overall to a 5% static stability;
2--i trim is the yaw trim angle of the horizontal stabilizer.

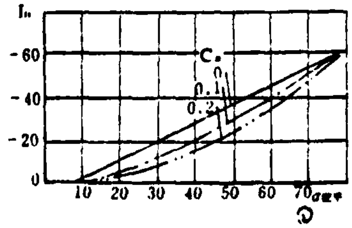


Figure 6. The influence of angle of attack and flap blowing on the equilibrium of the degree of yaw for the horizontal stabilizer.

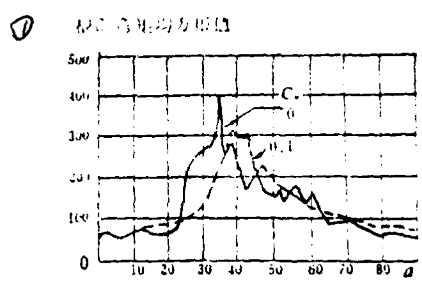
Figure 7 is the root-mean-square curve for the bending moment which is measured by placing strain gauges in the base section of the wing of the aircraft. From the wave-like movements of this curve, it is possible to derive the vibrations in the wing at various times. It can be seen from the results that the peak values of the curve which records the results for the case in which the blown flap technique is used are shifted toward even larger angles of attack; moreover, the order of magnitude of these peak values has also decreased. The significance of this simply is that the angles of attack which correspond to the dissipation of divergence of the vibration have been increased and the strength of the vibration has also been decreased. What is even more important than these aspects, however, is the very large increase in lift which corresponds to the occurrence of vibration (see Figure 5).

$C_\mu = 0, C_{L(FB)}^{(1)} = 1.2; C_\mu = 0.1,$ Key: (1) Vib.
$C_{L(FB)}^{(1)} = 1.68.$

This is an increase of almost 40%.

Experiments have also been carried out in which there was no use made of the leading edges on the wing and the jets were blown out from the main wing. The results from these tests were similar to the ones which we have already discussed. The only discrepancies were a certain variation in the magnitude of the results.

Figure 7. The influence of flap blowing the vibration amplitude



3. The employment of the blown flap technique at supersonic speeds

The blown flap technique can be used to control various types of separation formations when aircraft are in low speed flight. As a result of this, the technique is also capable of raising the

threshold of the onset of vibration. This point cannot easily be doubted. If this is the case at low speeds, is it possible to use this technique to improve the vibration characteristics of the same kinds of aircraft in subsonic flight? As a result of this improvement, can the coefficients of lift at high subsonic speeds be improved? Indeed yes. At present, there are already several aerodynamic designs which have given relatively good results. These designs include such features as wings whose leading edges have cracks or slits in them, secondary extensions forward of the edge of the main wing and next to the fuselage as we have already seen and the wing flaps. Wing twist is also included. However, all of these designs, to one degree or another, either add to the weight of the structures involved or increase their complexity. If we compare these designs to what will be described below, the simplicity of the structure involved in the use of the blown flap technique will appear even more outstanding. Below we will give a simple introduction of the results of wind tunnel experimentation of a transsonic application of the blown flap technique.

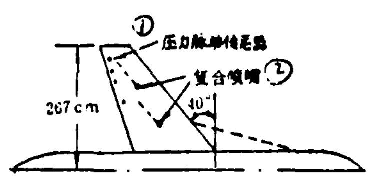
Figure 8 is an illustration of the model which was used in these tests. The extensions on the leading edge of the wing can be folded up; the sweepback angle of the leading edge of the wing is 40°, and the experiments were carried out in the ONERA S3MA intermittent type wind tunnel (experimental section 0.78x0.56 m). When a double jet flap nozzle for blowing which has the same overall $C\mu$ value as a corresponding single nozzle version was used, the experiments proved that this type of complex jet nozzle is capable of causing the effective range of the jet flow to be very greatly extended. The axis lines of these jet nozzles and the sweepback lines of the corresponding wings included angles of 10°. This is done because the jet flow has an enlarged range.

The results of these tests showed that flap blowing in a transsonic flow field has the ability to improve the lift and drag

capabilities and the force moment characteristics of a wing (the results in these areas were similar to those which were obtained during the low speed flights). Also it is capable of improving the shock-induced separation phenomenon and lessening the vibration of the wing.

In a transsonic flow field when the surface of the wing gives rise to shock waves, due to the fact that there is a very strong negative pressure gradient in front and behind the shock wave, it is very easy to induce boundary layer separation behind the shock wave. Changes in the configuration of the boundary layer can also cause irregular movements of the position of the shock wave, both forward and backward. This type of unstable, pulsating separating flow develops to a certain stage and then it gives rise to a vibration in the structure of the wing. As far as this phenomenon is concerned, excepting the fact that it is possible to observe it directly by the use of a flow spectrum from a wind tunnel, it is also possible to get an analysis of the spectral characteristics of this type of phenomenon by means of sensors installed on the wing in order to transmit data on air flow pulsations. It is also possible to install on the base of the wing strain gauges through which one can measure the periodic oscillations of the bending moment of the wing. There is also an extremely useful engineering method. One finds the point at which the curve which represents the changes in the axial force C_Λ as a function of changes in the angle of attack α bends. This point is taken as an indicator for the beginning of separation and "the onset of vibration" due to the shock wave see Figure 9.

Figure 8. An illustration of the complex jet nozzle on the model.
1--pressure pulsation sensor;
2--complex jet nozzles



When the angle of attack is small, the axial force corresponds to the drag. When α is increased, due to the fact that the contribution of the lifting forces to the axial force is increased, the overall axial force must gradually decrease in size; this process can even continue to the point where negative values can occur. After the appearance of separation on a wing as a result of the action of the shock wave, the increase in the lifting force slows down and the increase in the drag forces speeds up; as a result of this, the overall axial forces do not decrease again. When the point of boundary layer separation moves forward to shock wave, the separation layer suddenly bursts like bubbles the area of the separation is suddenly enlarged and the drag forces are suddenly increased. As a result of this, the axial forces suddenly increase in magnitude. In the wake of such a situation there are violent and unstable aerodynamic phenomena, like rapid motion of the shock wave and violent pulsations in the air flow. When such things occur, the wings involved will begin to vibrate obviously.

Figure 10 shows experimental results for M = 0.9 and the curve covers the range $C_{\Lambda} \sim \alpha$. From this figure it can be seen that the employment of the blown flap technique causes the angle of attack which corresponds to the point where the axial force curve bends to be very greatly pushed back. The value of the axial force in the area of the bend in the curve will also be much smaller. The significance of this is simply that the use of the blown flap technique has put off the occurrence of separation which is induced by the shock wave on the surface of the wing. At the same time, this raises the angle of attack and the lifting force values for the onset of vibration. The flow spectrum observations which correspond to these results are as follows. The blowing causes the area of separation caused by the shock wave to disappear. The reflection of this in the frequency spectrum analysis is to cause the mean-root-square value for the pulsations in air flow pressure levels to be reduced as are the peak values of the oscillating bending moment measured by the strain gauges in the base of the wing. Moreover, there is a

shift toward even larger angles of attack. All of these performance characteristics were verified at the same time time during these tests.

Figure 9. An illustration of basic wing vibration (M = 0.9)
1--lift; 2--drag;
3--oncoming flow; 4--axis line of the fuselage

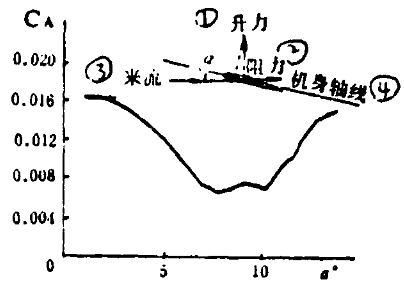
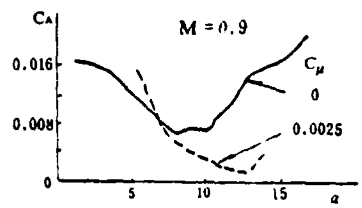


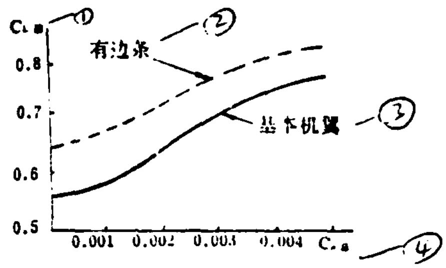
Figure 11 presents the influence of the flow coefficient on the vibration characteristics of wings equipped with the leading edges which we have already seen and the wings which are not equipped with this type of leading edge. These results are obtained for flow coefficients which apply when the blown flap technique is applied and M = 0.9.

Figure 10. Axial force characteristics of basic wings.



The vertical coordinates are the coefficients of lift which correspond to the bending point of the axial force involved (the areas involved are the same). The curves show that the use of the blown flap technique is very effective when used to increase the usable lift produced by an aircraft in supersonic flight. At the same time, the fact that the two curves shown are nearly parallel explains why the blown flap technique has the capability of improving the effectiveness of the leading edge of the wings themselves in supersonic flight.

Figure 11. The influence of blowing on the coefficients of lift which correspond to the bending point in the axial force
1--(illegible); 2--with additions on the front of the bases of the main wings; 3--the main wing by itself; 4--overall



Finally, it needs to be pointed out that the blowing momentum coefficients used during these experiments were all very small and they were all completely within practical ranges. The improvement which was achieved in the vibration characteristics also means that there was a reduction in the drag losses which were caused by aerodynamic separation; this improvement was only capable of partially compensating for the engine thrust which was lost due to generation of the blowing stream.

SUMMARY

It can be seen from the results of the research discussed above that the blown flap technique has already reached the stage where it is not only a technology which can be applied to aerodynamic designs in order to improve individual characteristics of aircraft. For multi-purpose, advanced fighter aircraft of the future, which will travel at speeds three times the speed of sound, it is a technique which is capable of being applied, either by itself or in coordination with other aerodynamic measures, in order to improve many types of aircraft characteristics for different flight speeds and flight configurations. These sorts of improvements will also make it possible to reduce funds required for these designs by making use of these improved characteristics.

The special characteristics or advantages of the blown flap technique include:

1. Its structure is simple and very well suited for applications. When one makes use of tue blown flap technique, there will be no excessive increase in the weight of the aircraft as a whole. It is possible, with relative ease, to install a blowing nozzle in any location on the aircraft where there is a need for blowing to be introduced and it is possible to use either single blowing nozzles or complex blowing nozzles.

2. It is possible to exploit changes in the blowing coefficients from various nozzles for longitudinal control and it is also possible to make use of asymmetrical blowing to exercise a lateral control.

3. The influence of using the blown flap technique on other characteristics of the aircraft as a whole is very small. The blown flap technique is capable of being employed entirely on the basis of a need for such a capability; when no such need exists, it is only necessary to close up the nozzles. On the other hand, such techniques as the use of the leading edge additions to the base of the main wings are measures which are always present during flight. Because of this, in certain types of flight configurations, these sorts of permanent features on the airframe of the aircraft can have disadvantages.

Finally, the key to whether or not the blown flap technique can be used is whether it "fits" on a high branching ratio engine.

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